

Effects of Broiler Litter Applied to No-Till and Tillage Cotton on Selected Soil Properties

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Improved understanding of the effects of broiler litter application to row crops as a source of nutrients on soil properties is required to predict the outcome of litter applications and prevent undesirable environmental impacts. This study was conducted on two separate commercial farms representing a no-till system at Coffeeville and a conventional-tillage system at Cruger in Mississippi to evaluate soil chemical, physical, and biological properties in response to 3 yr of broiler litter application with or without supplemental N. In each location, the experimental design was a randomized complete block with six treatments replicated four times. Treatments included broiler litter rates of 0, 4.5, and 6.7 Mg ha⁻¹ in some combination with 0, 34, and 67 kg N ha⁻¹. Commercial N-P-K fertilizer at the recommended rate was included. At the Coffeeville location, changes in soil characters increased with increasing broiler litter applications, and at the rate of 6.7 Mg ha⁻¹, soil pH, P, total N, total C, microbial biomass C, and soil aggregate stability significantly increased by 22, 20, 18, 20, 28, and 34%, respectively, as compared with commercial fertilizer treatment at the recommended rate. At the Cruger location, changes in soil character were less responsive to treatment applications. For the same broiler litter rate at Coffeeville and Cruger, no significant difference in the changes of soil character was obtained between a combination of broiler litter with supplemental N and broiler litter alone treatments. At both locations, broiler litter at rates >4.5 Mg ha⁻¹ with 67 kg ha⁻¹ supplemental N did not increase cotton lint yield and exceeded the crop N use potential as evidenced by increasing soil profile NO₃-N.

Abbreviations: AS, aggregate stability; BL, broiler litter; CT, conventional tillage; NT, no-till; TC, total C; TN, total N; UAN, urea-ammonium nitrate.

The broiler industry has experienced rapid expansion in the Southern Coastal Plain of Mississippi and in the coastal plain regions of other states in the Southeast. Mississippi ranks as the fourth largest broiler-producing state (USDA, 2004a), generating 1.1 million Mg yr⁻¹ of litter (Weaver and Souder, 1990) that contains 37 950 Mg N, 31 132 Mg P, and 22 095 Mg K each year, based on broiler litter (BL) N, P, and K concentrations (Patterson et al., 1998). In addition to nutrients, BL also contains approximately 39% C, which has the potential to improve soil quality. Because improvement of soil quality is the goal, measurement of changes in soil properties that might occur due to repeated land application of BL is needed. Broiler litter is a mixture of manure and bedding materials that has been used successfully as an alternative plant nutrient source to inorganic, commercial fertilizer.

The effect of manure on soil chemical properties has been reported in pastures and hayfields at heavy application rates (12–16 Mg ha⁻¹) (Kingery et al., 1994; Sistani et al., 2004). High rates of manure have resulted in P accumulation (Sharpley et

al., 1998), soil enrichment of NO₃-N (Edwards et al., 1992), and salt accumulation at the soil surface (Kingery et al., 1994). In a study on 'Coastal' bermudagrass, poultry application at the rate of 9 Mg ha⁻¹ yr⁻¹ increased extractable soil K, Ca, and Mg by 43, 32, and 73%, respectively, at the 0- to 15-cm depth as compared with inorganic fertilization (Evers, 1998; Franzluebbers et al., 2004). Long-term application of poultry litter to tall fescue (*Festuca arundinacea* Schreb.) significantly increased soil pH at the 0- to 15-cm soil depth. Extractable soil K, Ca, and Mg increased by twofold, and extractable Cu and Zn increased by threefold (Kingery et al., 1994). The effect of BL application on soil organic C in managed pasture is variable. Franzluebbers et al. (2001) reported no or little evidence of increased soil organic C concentration with BL addition to bermudagrass compared with inorganic fertilization. Kingery et al. (1994) reported that long-term application of BL to tall fescue resulted in greater soil organic C concentration at a depth of 0 to 15 cm. Sistani et al. (2004) reported that application of BL to bermudagrass at the rate of 16 Mg ha⁻¹ yr⁻¹ increased soil total C (TC) from 11.7 to 17.4 g kg⁻¹. Gao and Chang (1996) reported that long-term (18-yr) application of cattle feedlot manure increased surface soil (0–15 cm) cation exchange capacity, total organic C, and total N (TN). Besides affecting selected soil chemical properties, poultry litter additions may improve soil physical properties. In a 1-yr study on a fine-textured soil under rice production, Brye et al. (2004) reported that application of BL reduced near-surface soil bulk density.

In regions of intensive broiler production, BL is often over-applied to pastures and hayfields in close proximity to poultry house areas in an effort to "dispose" of the litter, thus threatening water quality and creating potential nutrient imbalance in

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soil fertility (Sharpley et al., 1998). To minimize these risks, producers must obtain additional land or use alternative crops to receive BL. One alternative that is being evaluated is litter application to row crops as a nutrient source. Several studies have been conducted to determine the effects of BL application on corn (*Zea mays* L.) (Wood et al., 1999; Brown et al., 1994), soybean (*Glycine max* L.) (Adeli et al., 2005), and cotton (*Gossypium hirsutum* L.)

growth and yield compared with inorganic commercial fertilizer (Burmester et al., 1991; Glover and Vories, 1998; Tewolde et al., 2005). Less research has been conducted to quantify the effects of BL application to row crops on soil property changes under no-till (NT) and conventional tillage (CT) systems. Because the BL N/P ratio is smaller than the N/P plant uptake ratio, BL application based on the N needs of row crops may result in soil accumulation of P and other elements that may influence nutrient imbalance with regard to soil fertility.

Although BL application rates to pasture and hayfield are generally high (16–20 Mg ha⁻¹ yr⁻¹) (Kingery et al., 1994; Sistani et al., 2004), recommended application rates for cotton generally are 4.5 to 5.4 Mg ha⁻¹ yr⁻¹ (Nyakatawa et al., 2001). It is unknown if long-term repeated annual BL application to cotton at the recommended rate changes soil quality character.

Compared with the recent concern for excessive P and salt accumulation with heavy application of poultry litter to pasture and hayfields, less research has focused on the changes in soil chemical, physical, and biological properties when BL is applied at moderate rates to cotton under different tillage systems.

The NT crop production system is becoming more common in the USA. It has been reported that as much as 86% of the cotton production in Mississippi is produced under NT or some form of reduced tillage system (Martin and Cooke, 2004). When applied in NT systems, BL acts as a mulch that reduces soil erosion while improving soil organic matter, conserving soil moisture, and providing nutrients for crops (Nyakatawa et al., 2001). In another study, Sims (1987) reported that poultry manure application to NT, where no incorporation is done, may reduce its effectiveness as a nutrient source because of potential N loss. Sims (1987) reported that poultry manure application resulted in significantly greater corn grain yield for a CT than a NT system. However, Sims did not report the effect of incorporated and nonincorporated poultry manure on soil chemical, physical, or biological properties. Surface application of BL to NT cotton could result in nutrient losses by volatilization and in runoff water shortly after application (Vories et al., 1999).

Implementation of conservation tillage systems such as NT and poultry litter application on cotton production in Mississippi, a state where poultry litter and cotton are dominant agricultural enterprises, may lead to significant changes in soil properties in the plow layer. These changes may have significant impacts on the environment and hence the sustainability of cotton production. In a study in which the effects of swine manure on corn and soybean nutrient uptake and yield were evaluated, Singer et al. (2004) reported that nutri-

Table 1. Soil and crop management and cultural practices used in each location.

Soil management†	Row spacing	Planting date	Cultivar used	Litter applied	N side-dressed	Date of defoliation	Date of soil sampling
Coffeeville							
NT, rainfed	97 cm	5/21/2002	DP 555	4/29/02	6/19/02	10/4/02	10/23/02
		5/2/2003	DP 555	5/13/03	6/24/03	9/30/03	10/21/03
		4/28/2004	DP 555	5/7/04	6/9/04	10/18/04	11/10/04
Cruger							
CT with irrigation	102 cm	4/19/2002	St 4892	4/18/02	5/23/02	9/3/02	9/16/02
		4/16/2003	St 4892	4/15/03	6/23/03	9/5/03	10/09/03
		4/19/2004	St 4892	4/9/04	6/8/04	9/13/04	10/06/04

† CT, conventional tillage; NT, no-tillage.

ent uptake alone may not be responsible for the yield response. They concluded that uptake efficiency from improved soil physical, chemical, and biological properties may interact to increase yield in crops produced on manure-amended soil.

Keeping soil characteristics in good condition is important to ensure satisfactory crop growth and yield. The objective of this study was to quantify the effect of long-term BL with and without supplemental N fertilizer applied to cotton on soil chemical, physical, and biological properties.

MATERIALS AND METHODS

The experiment was conducted on two separate commercial cotton fields at Coffeeville and Cruger locations in Mississippi representing NT and CT systems, respectively. Experimental plots were established at both locations in 2002. The locations are different in terms of cultural practices such as tillage, row spacing, cotton cultivar, planting date, litter application date, harvest date, and commercial fertilizer treatments. Experiments were independent from each other, and measured variables in the two locations were not compared with each other but evaluated separately (two separate experiments). Because the purpose of this study was to determine the long-term effects of BL application on soil chemical, physical, and biological properties, only samples taken at the end of 3 yr were used.

At Coffeeville, soil is an Ariel silt loam soil (coarse-silty, mixed, thermic Fluventic Dystrochreps) representing an NT system. The cultural practices related to this location are shown in Table 1. After picking, cotton stalks were shredded. Plots were not cultivated but were over seeded with wheat as a cover crop after picking cotton in the fall each year. The wheat stands were killed using glyphosate [N-phosphomethyl glycine] approximately 2 wk before planting cotton in spring. Individual plot dimensions were 73 m long with eight rows having a row spacing of 97 cm. The cotton field at this location was under a rainfed condition.

At Cruger, the soil is a Dubbs silt loam soil (fine-silty, mixed, active, thermic Typic Hapludalfs). After picking, cotton stalks were shredded. The cultural practices related to this location are shown in Table 1. Plots were prepared by CT, which included in-row subsoiling in the fall to reduce soil compaction. The in-row subsoiling implement loosened an area approximately 8 cm wide and 40 cm deep directly under the row, disrupting the possible hardpan. Attachments on the tool bar hipped the rows and firmed up the beds in spring before planting cotton. Individual plot dimensions were 119 m long, with four rows having a row spacing of 102 cm. Cotton was irrigated as needed using a center pivot irrigation system. Management and cultural practices used in each location are shown in Table 1. At both locations in 2002, background soil samples were taken at the depth of

Table 2. Initial chemical and physical characteristics of soils at the 0- to 15-cm depth before plots were prepared for treatments in April 2002.

Parameter	Ariel (Coffeerville)	Dubbs (Cruger)
pH	5.7	5.6
OM, %	1.53	1.51
Biomass C, mg kg ⁻¹	208	153
P, mg kg ⁻¹	6.8	40.4
K, mg kg ⁻¹	49	233
Total N, g kg ⁻¹	0.88	0.79
NH ₄ , mg kg ⁻¹	24	51
NO ₃ , mg kg ⁻¹	14	13
Texture	Silt loam	Silt loam
Bulk density, g cm ⁻³	1.35	1.27

0 to 15 cm before conducting the experiments and analyzed. Initial soil chemical and physical characteristics are shown in Table 2.

At Coffeerville and Cruger, the experimental design was a randomized, complete block with six treatments replicated four times. For both locations, treatments included annual BL rates of 0, 4.5, and 6.7 Mg ha⁻¹ supplemented with inorganic N. Treatments receiving BL at the rate of 6.7 Mg ha⁻¹ were applied with and without 34 kg N ha⁻¹ as supplemental N, and the 4.5 Mg ha⁻¹ BL treatments were applied with and without 67 kg N ha⁻¹ supplemental N. The source of supplemental N was urea-ammonium nitrate (UAN) solution (32% N).

The UAN solution (32% N) was applied at early squaring stage as a sidedress using a commercial liquid fertilizer applicator equipped with coulters that opened slots 15 to 20 cm away from the row center. The UAN solution was injected into the slot immediately after it opened. A commercial fertilizer treatment was also included at each location with rates of N, P, and K determined by soil test and recommendations of The Mississippi Soil Test Laboratory. At Cruger, the recommended commercial fertilizer treatment included 135–0–168, 135–45–118, and 135–0–112 kg N–P₂O₅–K₂O ha⁻¹ in 2002, 2003, and 2004, respectively. At Coffeerville, the recommended commercial fertilizer treatment included 112–67–67, 118–45–90, and 118–0–135 kg N–P₂O₅–K₂O ha⁻¹ in 2002, 2003, and 2004, respectively. The commercial N–P–K fertilizer source was ammonium nitrate (34–0–0), super phosphate (0–46–0), and Muriat of potash (0–0–60). Phosphorus and K were applied before planting. Fertilizer N was applied as a split application (half at planting and half at early squaring). Commercial fertilizer at the recommended rate was applied by hand.

Broiler litter was applied within 10 d before planting at Cruger and within 25 d before or after planting at Coffeerville. At both locations, BL was broadcast in spring using a commercial fertilizer spreader equipped with ground speed sensing radar, an electronic scale, and a rate-control computer system (Barrons and Brothers, Inc., Gainsville, GA). Applied litter was incorporated into the soil within

1 d of application at Cruger but was left on the surface at Coffeerville because this location is NT. Broiler litter was obtained from a commercial broiler producer in southern Mississippi in 2002 and from a commercial broiler producer in central Mississippi in 2003 and 2004. The litter may have been stored under shade near the broiler houses for several weeks before use.

Total N and TC content in BL was determined on air-dried samples using an automated dry combustion C/N analyzer (Model NA 1500 NC; Carlo Erba, Milan, Italy). Total P content of BL was determined by dry-ashing a 1-g sample according to procedures outlined by Issac and Kerber (1977) and measured using inductively coupled argon plasma spectrophotometry (Thermo Jarrel Ash; Iris Advantage ICP, 40669, Houghton, MI). Chemical analysis of the BL for each location is shown in Table 3.

To determine the extent of nitrate movement in the soil profile, soil was sampled after picking cotton from the center of each plot to 90 cm depth and divided into 0- to 15-, 15- to 30-, 30- to 60-, and 60- to 90-cm increments. Ten cores (2.5 cm in diameter) were taken and composited for each plot and depth in the field and mixed thoroughly, and a representative subsample was taken for analysis. Soil samples were air dried, ground to pass through a 2-mm sieve, and stored for chemical analysis. Soil samples were analyzed for TC, TN, Mehlich III P, nitrate, ammonium, pH, total microbial biomass C, total microbial biomass N, and soil aggregate stability (AS). Soil bulk density was determined at each location in 2002 (initial) and in 2004 after 3-yr BL application. Soil and BL pH were determined on the same solution to solid ratio (1:2.5). Soil and BL pH were determined in water using a glass electrode and 1:2.5 soil/BL to water ratio (pH/EC/TDS meter model H19813-0; Hanna, Woonsocket, RI). Total C and TN for soil were determined from air-dried, finely ground soil using an automated dry combustion C/N analyzer (Model NA 1500 NC; Carlo Erba, Milan, Italy). Soil organic matter was calculated from TC (percent of organic matter = TC × 1.72). Soil texture was determined by the method of Day (1965). Soil NO₃-N and NH₄-N were determined by extracting soil with 2 M KCl (Keeney and Nelson, 1982) and analyzed for inorganic N (NH₄⁺ and NO₃⁻) using a Lachat instrument (QC 8000 flow injection analyzer; Lachat, Loveland, CO). These samples were also extracted using Mehlich-III extractant (Mehlich, 1984) and analyzed for plant-available P using inductively coupled argon plasma spectrophotometry. Soil biomass C was determined using the fumigation-extraction method of Vance et al. (1987). Twenty-five grams of moist soil were weighted into 100-mL glass beakers and fumigated with chloroform for 24 h in a vacuum desiccator. After chloroform removal, the soils were extracted with 100 mL of 0.5 M K₂SO₄ for 30 min. Nonfumigated soils were extracted in a similar way. The organic C in the soil extract was measured by dichromate oxidation (Kalembasa and Jenkinson, 1973), and the soil microbial biomass C was calculated as the difference between the concentration

Table 3. Nutrient analysis of broiler litter applied to both locations each year.

	2002		2003		2004		Average	
	Cruger	Coffeerville	Cruger	Coffeerville	Cruger	Coffeerville	Cruger	Coffeerville
C, g kg ⁻¹	251	259	232	237	296	248	260	248
pH	7.05	7.10	7.21	7.16	7.32	7.42	7.19	7.23
Moisture, %	34.2	22.9	39.1	28.0	26.1	26.5	33.1	25.8
Total N, g kg ⁻¹	23.6	33.5	26.3	28.1	26.0	31.3	25.3	31.0
Total P, g kg ⁻¹	16.9	18.9	10.3	12.7	11.8	12.8	13.0	14.8
K, g kg ⁻¹	24.8	30.7	25.0	29.2	28.9	29.1	26.2	29.7

of TC in fumigated and nonfumigated soils. Soil microbial biomass N was measured by the fumigation extraction method as described by Brooks et al. (1985). Soil was fumigated and extracted with 0.5 M K₂SO₄ in the same manner as for microbial biomass C. Total N

Table 4. Soil chemical, physical, and biological properties at the 0- to 15-cm depth at Coffeerville after 3 yr of broiler litter and chemical fertilizer application, fall 2004

Treatments		pH	Total N	Total C	C/N ratio	MBC†	MBN‡	Biomass C/N ratio	AS§	D _b ¶
			—g kg ⁻¹ —			—mg kg ⁻¹ —			%	g cm ⁻³
Broiler litter	Fertilizer N									
0	0	5.50	0.70	7.7	11.0	288	29	9.9	20	1.32
4.5	0	6.21	0.87	9.4	10.8	374	31	12.1	25	1.31
6.7	0	6.61	0.99	10.6	10.7	423	34	12.4	29	1.30
4.5	67	5.99	0.89	10.2	11.3	408	33	12.4	27	1.31
6.7	34	6.31	1.06	10.8	10.2	429	34	12.6	30	1.30
0	118	5.15	0.81	8.5	10.5	305	28	10.8	19	1.33
LSD _(0.05)		0.33	0.09	0.65	1.16	39.6	3.1	1.11	3.3	0.12

† MBC, microbial biomass C.

‡ MBN, microbial biomass N.

§ AS, aggregate stability.

¶ D_b, bulk density.

in the K₂SO₄ extracts from fumigated and nonfumigated soils was determined according to Pruden et al. (1985). Microbial biomass N was calculated as the difference between the concentration of TN in fumigated and nonfumigated soils. Soil AS was determined on 2-mm sieved air-dried soil by a modified turbidimetric method (Williams et al., 1966).

The General Linear Models procedure in SAS (SAS Institute, 1996) was used to perform ANOVA. Analysis of variance was performed for each location separately. Statistical differences of means were compared with Fisher's protected LSD at a probability level of 0.05.

RESULTS AND DISCUSSION

Both locations had similar weather patterns each season. There were slightly cooler temperatures at Coffeerville than at Cruger. The Coffeerville location received more rain than Cruger in the first 2 yr. The cotton at Cruger received supplemental irrigation as needed via an overhead center pivot, whereas the cotton at Coffeerville was rainfed. Growing season rainfall (summed from May to September) was 313, 421, and 726 mm in 2002, 2003, and 2004 at Cruger and 589, 596, and 717 mm in 2002, 2003, and 2004 at Coffeerville, respectively.

Coffeerville Location

Soil pH

After 3 yr of BL applications, soil pH at the 0- to 15-cm depth significantly increased with increasing application rate and ranged from 5.15 for the fertilizer N rate to 6.61 with 6.7 Mg BL ha⁻¹ (Table 4). No significant difference in soil pH was obtained between BL and the combination of BL with supplemental N. The pH increased in soils amended with BL, possibly due to the effect of calcium carbonate (CaCO₃) added in the poultry diet as source of calcium (Hue, 1992), which

may have been present in the applied BL. Hue (1992) reported that broiler and turkey feed may contain 1.33% CaCO₃, which is passed through the bird and ends up in the manure. Surface (0–15 cm) soil pH decreased by 6% in plots receiving only commercial fertilizer as compared with the control (Table 4). The difference is small but significant. Declining pH with inorganic fertilizer was likely due to the acidifying effects of the long-term addition of N fertilizer (Bowman and Halvorson, 1998). The acidity (H⁺) release through nitrification of NH₄, supplied inorganically or as organic compounds (Franzluebbers et al., 2004), and subsequent leaching of cations like Ca²⁺, Mg²⁺, or K⁺ from the soil are responsible for declining pH (Bouman et al., 1995). At the 15- to 30-cm depth, soil pH was not affected by BL or chemical fertilizer (Table 5).

Total Soil C

At the end of 3 yr, total soil C concentration increased with increasing BL litter applications at the surface 0- to 15-cm soil depth and ranged from 7.7 with the control (no BL/commercial fertilizer) to 10.8 g kg⁻¹ with 6.7 Mg BL ha⁻¹ when supplemented with 34 kg N ha⁻¹ (29% increase) (Table 4). This net increase of 3.1 g kg⁻¹ C stored in soil organic matter accounts for a small percentage of the TC applied in BL. Our results are in agreement with the work by Schlegel (1992), who reported a smaller increase (0.26%) in soil organic matter after

Table 5. Soil chemical, physical, and biological properties at the 15- to 30-cm depth at Coffeerville after 3 yr of broiler litter and chemical fertilizer application, fall 2004

Treatments		pH	Total N	Total C	C/N ratio	MBC†	MBN‡	C/N ratio	D _b §
			—g kg ⁻¹ —			—mg kg ⁻¹ —			g cm ⁻³
Broiler litter	Fertilizer N								
0	0	5.24	0.36	3.52	9.8	143	11	13.0	1.40
4.5	0	5.29	0.33	3.25	9.8	146	12	12.2	1.38
6.7	0	5.30	0.36	3.27	9.1	133	11	12.1	1.38
4.5	67	5.14	0.38	3.57	9.4	136	11	12.4	1.38
6.7	34	5.36	0.39	3.38	8.7	132	11	12.0	1.37
0	118	5.32	0.37	3.42	10.1	133	12	11.1	1.39
LSD _(0.05)		0.24	0.04	0.38	0.6	18	1.2	1.5	0.09

† MBC, microbial biomass C.

‡ MBN, microbial biomass N.

§ D_b, bulk density.

application of cattle manure compost for three consecutive years at an annual rate of 16 Mg ha⁻¹. Application of BL with or without supplemental N significantly increased total soil C as compared with commercial fertilizer (Table 4). The combination of 6.7 Mg ha⁻¹ BL with 34 kg ha⁻¹ supplemental N significantly increased total soil C by 22% as compared with commercial fertilizer. However, at the similar rate, no significant difference in total soil C was obtained between BL alone and the combination of BL and supplemental N. The use of BL singly or supplemented with chemical fertilizer N plays a key role in the potential sequestering of C and in the building up soil fertility. Our results are in agreement with those of Parker et al. (2002), who reported that application of poultry litter to cotton at the rate of 200 kg N ha⁻¹ (6.7 Mg BL ha⁻¹) significantly increased soil C by 26% at the 0- to 15-cm depth as compared with the control. Wood et al. (1996) and Franzluebbers et al. (2001) reported no difference in soil organic C concentration after 3 yr of BL applications to corn and bermudagrass.

Total soil C concentrations significantly decreased with depth. No significant difference in soil C concentration at the 15- to 30-cm depth was obtained among treatments (Table 5). Averaged across treatments, TC was 64% higher in the 0- to 15-cm depth than in the 15- to 30-cm depth. Reduction in total soil C at Coffeerville under the NT system with increasing soil depth can be explained by the accumulation of organic residues from cotton and BL in the upper soil layer.

Total Soil N

Total soil N concentration at the 0- to 15-cm soil depth significantly increased with increasing BL applications at the Coffeerville location and ranged from 0.70 g kg⁻¹ with the control (no BL/commercial fertilizer) to 1.06 g kg⁻¹ with application of 6.7 Mg BL ha⁻¹ when supplemented with 34 kg N ha⁻¹ (Table 4). Soils with a BL application at the rate of 6.7 Mg ha⁻¹ had 19% higher TN than the soils receiving chemical fertilizer only (Table 4). No significant difference in total soil N was obtained between BL alone and a combination of BL with supplemental N. Total soil C and N followed the same pattern with application of BL. Our results are in agreement with the work of Regonald (1988), who reported that TN in the soils receiving organic fertilizer was greater than in soils receiving chemical fertilizer. No significant difference in C/N ratio was obtained between soils receiving BL or chemical fertilizer. In contrast to our results, Kulvinder et al. (2005) reported a lower C/N ratio with the application of manures as compared with chemical fertilizer.

Total soil N concentration strongly decreased with depth (Table 5). At the 15- to 30-cm depth, no significant difference in total soil N concentration was obtained among treatments. Averaged across treatments, soil TN concentration was 58% higher in the 0- to 15-cm depth than in the 15- to 30-cm depth.

Soil Microbial Biomass C

Soil microbial biomass C at the 0- to 15-cm depth was significantly affected by BL applications at Coffeerville (Table 4). Soil microbial biomass C ranged from 288 mg kg⁻¹ for the control (no BL or fertilizer applied) to 429 mg kg⁻¹ with the application of 6.7 Mg BL ha⁻¹ with 34 kg ha⁻¹ supplemental N (33% increase) (Table 4). This can be related primarily to the

quantity and quality of C substrates (Islam and Weil, 2000a) in soils collected from treatments receiving BL. Greater amounts of organic matter in BL could have provided the labile C substrates (Islam and Weil, 2000b) needed for maintenance of the larger microbial biomass C in BL-amended soils. No significant difference in microbial biomass C was obtained between BL alone or with the combination of BL with supplemented N (Table 4). Soils receiving BL with or without supplemental N had greater microbial biomass C than soils receiving chemical fertilizer only. For example, application of BL at the rate of 6.7 Mg ha⁻¹ with 34 kg ha⁻¹ supplemental N increased soil microbial biomass C by 29% as compared with chemical fertilizer. The lower quantity of microbial biomass C of soils receiving commercial fertilizer compared with that found in BL treatments was possibly due to the lower availability of C in long-term, chemically fertilized soils, indicating that C is a limiting factor for development of soil microbial biomass (Table 4). Our results are consistent with other reports that have shown that soils receiving animal manures have a larger microbial biomass C pool than the same soils receiving only chemical fertilizers (Sommerfield and Chang, 1985; Barkle et al., 2000). Related to the role of C in the development of microbial biomass C, Fauci and Dick (1994) reported that the addition of organic residue to the soils significantly increased microbial biomass C and N.

Soil Microbial Biomass N

Soil microbial biomass N also increased with the addition of BL as compared with the control (no BL added) and chemical fertilizer at the Coffeerville location (Table 4). No significant difference in microbial biomass N was observed between BL alone and the combination of BL with supplemental fertilizer N. The biomass C/N ratio had the lowest value for the control and chemical fertilizer and the highest value for BL litter applications. No significant difference in biomass C/N ratio was observed between BL alone and the combination of BL with supplemental N (Table 4). Soil microbial biomass C and N at the 15- to 30-cm soil depth (Table 5) substantially decreased as compared with the surface 0- to 15-cm soil depth, possibly due to reduction of C at the lower depth. The results are in agreement with the work of Anderson and Domsch (1985), who reported that the availability of C is considered to be a limiting factor for the development of microbial biomass.

Soil Aggregate Stability

At the end of 3 yr, BL application increased soil AS at Coffeerville (Table 4). Aggregate stability from plots with application of 6.7 Mg BL ha⁻¹ with 34 kg ha⁻¹ supplemental N were 38% greater than the control plots (Table 4). The lowest value for AS was obtained with the application of chemical fertilizer. Increased soil AS under BL applications at the Coffeerville location could be related to an increase in organic C in the soil, which would increase biological activities and produce more organic binding or stabilizing agents for soil macroaggregation (Oades, 1984; Angers et al., 1992). Then, microaggregation may retain C content in soil that is physically protected from microbial decomposition (Robertson et al., 1991). Inorganic fertilizer was less effective in soil stabilization than BL treatments (Table 4).

Soil Bulk Density

Soil bulk density was determined before conducting the experiment in 2002 and at the end of 3 yr in 2004 for the 0- to 15- and 15- to 30-cm depths. Regardless of increasing soil TC concentrations near the soil surface, soil bulk density was unaffected by the BL applications at both locations (Tables 4 and 6). The amount of organic matter applied from broiler applications to these soils, with an average original organic matter of 15.2 g kg^{-1} (see Table 1), may not be enough to make a significant difference in soil bulk density (Tables 4 and 5). Our results are in agreement with the results of Brye et al. (2004), who measured soil bulk density in three locations receiving poultry litter and reported that poultry litter did not significantly affect soil bulk density in the top 10 cm at any of the three study locations.

Residual Soil $\text{NO}_3\text{-N}$

Post-harvest residual $\text{NO}_3\text{-N}$ concentrations in the soil profile at Coffeeville are shown in Fig. 1. Application of BL and chemical fertilizer resulted in increasing soil residual $\text{NO}_3\text{-N}$ as compared with the untreated control. No significant difference in residual soil $\text{NO}_3\text{-N}$ occurred among the broiler treatment with or without supplemental N, except for the 6.7 Mg ha^{-1} BL with 34 kg ha^{-1} supplemental N, in which residual $\text{NO}_3\text{-N}$ increased by 32% as compared with BL alone at the same rate. This could be due to the fact that 6.7 Mg ha^{-1} BL with 34 kg ha^{-1} supplemental N treatment was not as effective as the 4.5 Mg ha^{-1} BL with 67 kg ha^{-1} supplemental N treatment at increasing cotton yield (Table 6). Thus, application of BL at rates greater than 4.5 Mg ha^{-1} BL with 67 kg ha^{-1} supplemental N did not enhance cotton lint yield and possibly exceeded the crop nutrient use potential as evidenced by increasing $\text{NO}_3\text{-N}$ concentration in the top 15-cm soil profile (Fig. 1). Our results are different from the results of Gascho et al. (2001), who reported that, in a Tifton loamy sand soil, $\text{NO}_3\text{-N}$ level did not increase with BL rate for any of the depths sampled. Bissonnais and Arrouays (1997) reported that development of soil infiltration capacity is related to AS. Increased AS due to BL application at the Coffeeville location under the NT system (Table 4) may increase soil infiltration capacity and result in downward movement of $\text{NO}_3\text{-N}$ with water to the lower soil depth. In our study, regardless of AS at the 0- to 15-cm soil depth, no leaching $\text{NO}_3\text{-N}$ was observed, and $\text{NO}_3\text{-N}$ concentration was mainly limited to the top 15 cm of the soil profile.

Soil Phosphorus

Mehlich 3-extractable P distribution into the soil profile at Coffeeville is shown in Fig. 2. Before the experiment, soil P tested low (8.3 mg kg^{-1}) at Coffeeville (Table 1). In 2004, after 3 yr of BL applications, soil P concentration at the 0- to 15-cm depth increased linearly ($P < 0.001$) with increasing BL applications ($y = 7.98 + 6.2x$; $r^2 = 0.98$). The net increase in Mehlich 3-extractable soil P ranged from 25 mg kg^{-1} soil (74% increase) to 42 mg kg^{-1} soil (83% increase) for BL application at the rate of 4.5 and $6.7 \text{ Mg ha}^{-1} \text{ yr}^{-1}$, respectively. At the end of 3 yr, the cumu-

Table 6. Effects of broiler litter with and without supplemental N on cotton lint yield grown at Cruger under conventional tillage and at Coffeeville under no-till systems.

Treatment		Cruger			Coffeeville		
Broiler litter	Fertilizer N	2002	2003	2004	2002	2003	2004
Mg ha^{-1}		kg ha^{-1}					
0	0	1478	928	728	867	724	748
4.5	0	1595	1355	1198	1088	1182	1042
6.7	0	1643	1484	1424	1269	1405	1252
4.5	67	1718	1725	1628	1383	1565	1401
6.7	34	1693	1670	1566	1293	1440	1212
0	135	1670	1771	1601	—	—	—
0	118	—	—	—	1282	1278	1295
$\text{LSD}_{(0.05)}$		161	152	139	122	130	110

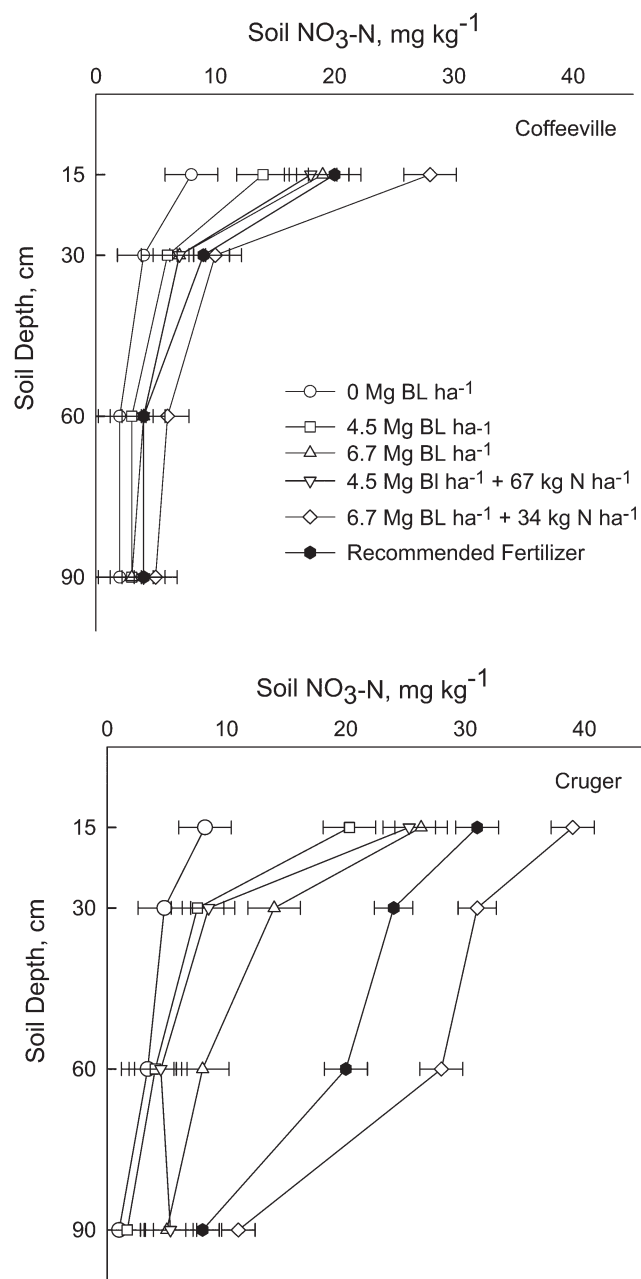


Fig. 1. Effects of broiler litter supplemented with and without fertilizer N and commercial fertilizer application rates on residual soil $\text{NO}_3\text{-N}$ concentrations at the Coffeeville and Cruger locations at the end of 3 yr in 2004.

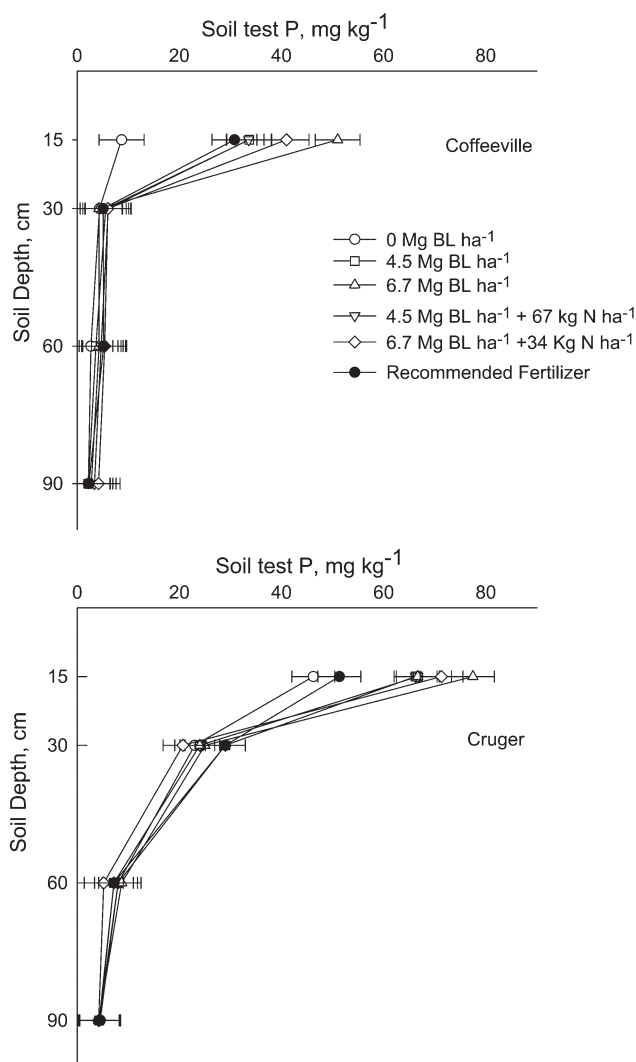


Fig. 2. Effects of broiler litter supplemented with and without fertilizer N and commercial fertilizer application rates on soil P concentrations at the Coffeerville and Cruger locations at the end of 3 yr in 2004.

relative P rates applied to the soil were 200 and 298 kg ha⁻¹ for BL rates of 4.5 and 6.7 Mg ha⁻¹, respectively. Broiler litter applications with or without supplemental N increased extractable soil P concentrations at the surface (0–15 cm) soil as compared with

the untreated control. No significant difference in soil P levels in the surface 0 to 15 cm was obtained between BL alone or in the combination of BL with supplemental N. It seems that the efficiency of seed cotton in P removal from N-based BL application is not large enough to prevent P accumulation. Tewolde et al. (2006) reported that, regardless of the tillage system, BL application at a rate greater than 2.2 Mg ha⁻¹ (30 kg P ha⁻¹) did not increase cotton P uptake resulting in P accumulation at the soil surface. Dorahy et al. (2004) reported that average P uptake values at physiologic cut-out and P removal in seed cotton were 21 and 15 kg ha⁻¹, respectively.

Cruger Location

Soil pH

With CT at this location, only BL at the high rate (6.7 Mg ha⁻¹) significantly increased soil pH as compared with the control (0 Mg ha⁻¹) (Table 7). No significant difference in soil pH was obtained between BL alone and the combination of BL with supplemental N. Application of chemical fertilizer at this location did not have a significant effect on soil pH. Soil pH was not affected by BL application or by the combination of BL with chemical fertilizer N at the 15- to 30-cm soil depth (Table 8).

Total Soil C

Total soil C increased with increasing BL application at the 0- to 15-cm depth and ranged from 7.5 with the control (no BL/commercial fertilizer) to 8.3 g kg⁻¹ with 6.7 Mg BL ha⁻¹ (10% increase) (Table 7). At a similar BL rate, no significant difference in total soil C was obtained between BL alone and the combination of BL with supplemental N except with BL at the rate of 6.7 Mg ha⁻¹, in which soil had greater TC than the combination of this rate with 34 kg ha⁻¹ supplemental N (Table 7). Broiler litter application at rate of 6.7 Mg ha⁻¹ resulted in greater TC (7%) than chemical fertilizer. Our results are in agreement with the results of Rasmussen et al. (1998), who reported that application of organic fertilizer to the soil resulted in increased soil C.

Total Soil N

Total soil N at the 0- to 15-cm depth significantly increased with increasing BL applications (Table 7). The total soil N concentration ranged from 0.62 g kg⁻¹ with the control

Table 7. Soil chemical, physical, and biological properties at the 0- to 15-cm depth at Cruger after 3 yr of broiler litter and chemical fertilizer application, fall 2004.

Treatments		pH	Total N	Total C	C/N ratio	MBC†	MBN‡	C/N ratio	AS§	D _b §
Broiler litter	Fertilizer N		—g kg ⁻¹ —			—mg kg ⁻¹ —			%	g cm ⁻³
0	0	5.68	0.61	7.5	11.7	227	15.3	14.8	15	1.23
4.5	0	5.79	0.69	7.9	11.4	236	16.3	14.5	18	1.22
6.7	0	5.96	0.77	8.3	10.5	243	17.0	14.3	18	1.21
4.5	67	5.64	0.68	7.7	11.0	228	15.9	14.3	19	1.22
6.7	34	5.76	0.71	7.9	10.9	227	16.3	14.5	19	1.22
0	135	5.56	0.69	7.7	11.0	233	16.3	14.3	13	1.25
LSD _(0.05)		0.26	0.07	0.36	1.32	14.6	1.33	0.89	1.8	0.09

† MBC, microbial biomass C.

‡ MBN, microbial biomass N.

§ AS, aggregate stability.

¶ D_b, bulk density.

Table 8. Soil chemical, physical, and biological properties at the 15- to 30-cm depth at Cruger after 3 yr of broiler litter and chemical fertilizer application, fall 2004.

Treatments		pH	Total N	Total C	C/N ratio	MBC†	MBN‡	C/N ratio	D _b §
Broiler litter Mg ha ⁻¹	Fertilizer N kg ha ⁻¹		—g kg ⁻¹ —			—mg kg ⁻¹ —			g cm ⁻³
0	0	4.51	0.52	4.43	8.5	135	9.3	14.5	1.29
4.5	0	4.53	0.53	4.57	8.6	143	10.3	13.9	1.28
6.7	0	4.57	0.59	4.62	7.8	134	9.4	14.3	1.28
4.5	67	4.42	0.58	4.87	8.4	136	9.2	14.8	1.28
6.7	34	4.43	0.59	4.78	8.1	147	10.4	14.1	1.27
0	135	4.56	0.54	4.79	8.9	142	9.9	14.3	1.29
LSD _(0.05)		0.25	0.08	0.36	2.4	13.1	1.4	1.53	0.11

† MBC, microbial biomass C.

‡ MBN, microbial biomass N.

§ D_b, bulk density.

(no BL/commercial fertilizer) to 0.77 g kg⁻¹ with the application of 6.7 Mg BL ha⁻¹ (Table 7). No significant difference in total soil N was observed between BL alone and the combination of BL with supplemental N treatments. Application of BL only at the rate of 6.7 Mg ha⁻¹ increased total soil N by 10% as compared with commercial fertilizer treatment (Table 7). Soil TC and TN followed the same pattern with application of BL. There was no significant difference in the C/N ratio between soil that received BL or soil that received chemical fertilizer. Soil TN concentration decreased with depth (Table 8). At the 15- to 30-cm soil depth, no significant difference in soil TN concentration was obtained among treatments.

Soil Microbial Biomass C

Soil microbial biomass C at the Cruger location was not influenced by BL or chemical fertilizer applications. Only at the high BL application rate (6.7 Mg ha⁻¹) were soil microbial biomass C and N significantly greater than the control (no BL or chemical fertilizer applied) (Table 7). Soil microbial biomass C at the 15- to 30-cm depth was substantially lower than the surface 0- to 15-cm depth (Table 8). Because the availability of organic C is considered a limiting factor of microbial biomass C (Anderson and Domsch, 1985), substantial reduction in microbial biomass C at the 15- to 30-cm depth was possibly due to the lower availability of C. No significant differences in soil microbial biomass C occurred among treatments at the 15- to 30-cm soil depth, indicating limited microbial activity in the lower depth.

Soil Aggregate Stability

Broiler litter application increased soil AS at the 0- to 15-cm soil depth at Cruger (Table 7). No significant difference in soil AS was obtained between BL alone and the combination of BL with supplemental N. Averaged across broiler BL treatments with or without supplemental N, soil AS increased by 35% as compared with commercial fertilizer (Table 7). The lowest value for AS was obtained with the application of chemical fertilizer.

Residual Soil NO₃-N

Post-harvest residual soil NO₃-N concentrations at Cruger are shown in Fig. 1. At the end of 3 yr, residual soil NO₃-N for all treatments where N was applied was higher at the 0- to

15-cm depth than the untreated control. The highest residual soil NO₃-N was in the chemical fertilizer and the 6.7 Mg ha⁻¹ BL with 34 kg ha⁻¹ supplemental N treatments. In terms of cotton lint yield, the 6.7 Mg ha⁻¹ BL with 34 kg ha⁻¹ supplemental N treatments was not as effective as the 4.5 Mg ha⁻¹ BL with 67 kg ha⁻¹ supplemental N in 2004 (Table 6). It seems that application of BL at rates greater than 4.5 Mg ha⁻¹ with 67 kg ha⁻¹ supplemental N did not enhance cotton yield (Table 8) and exceeded the crop N use potential as evidenced by soil profile NO₃-N concentrations (Fig. 1). In 2004, for chemical fertilizer and BL at the rate of 6.7 Mg ha⁻¹ with 34 kg ha⁻¹ supplemental N, there was a significant increase in residual NO₃-N at the 30- to 60-cm depth (Fig. 1). The presence of NO₃-N at the 30- to 60-cm depth likely occurred because more available N was supplied than was required by cotton at the lint yields attained or N released from BL mineralization during the growing season did not synchronize with plant N demand and leached to the lower depth. Although the irrigation management by the farmer was devised to minimize excess water applications during the growing season to minimize leaching below the root zone, some downward movement of nitrate might have occurred at this location.

Soil Phosphorus

Before the experiment, soil test P levels were high (46.8 mg kg⁻¹) at the Cruger location, as indicated by the Mississippi Soil Testing Laboratory for cotton (see Table 1). At the end of 3 yr, Mehlich III-extractable soil P increased linearly ($Y = 45 + 4.6X$; $r^2 = 0.96$) with increasing BL applications. The net increase in extractable soil P ranged from 20 to 31 mg kg⁻¹ for BL at rates of 4.5 and 6.7 Mg ha⁻¹ yr⁻¹, respectively. At the end of 3 yr, the cumulative P rate applied to the soil was 176 and 261 kg ha⁻¹ for BL rates of 4.5 and 6.7 Mg ha⁻¹, respectively. Broiler litter applications with or without supplemental N increased extractable soil P concentrations at the surface (0–15 cm) soil as compared with the untreated control. No significant difference in soil P levels in the surface 0 to 15 cm was observed between BL alone and the combination of BL with supplemental N. Extractable soil P increased by 40% and 10% with BL application at the rate of 6.7 Mg ha⁻¹ and commercial fertilizer at the recommended rate compared with the untreated control, respectively (Fig. 2). Regardless of initial soil

test P level (40 mg kg⁻¹) (see Table 2) and irrigation of cotton, no downward movement of P was obtained, and P was mainly accumulated in the top 15 cm soil depth (Fig. 2).

SUMMARY

Our results at the end of 3 yr at the Coffeeville location demonstrate that soil samples (0–15 cm) of the BL-amended plots had significantly greater pH, P, TN, TC, microbial biomass C, and AS compared with plots receiving chemical fertilizer alone. Soil AS had the lowest value where commercial fertilizer was applied, indicating a positive correlation between soil C concentrations and soil AS. At Cruger, soil characters were less responsive to treatment applications. Soil P was greatest in the 0- to 15-cm depth with tillage at Cruger and NT at Coffeeville and increased by 40% and 83% as compared with the control, respectively. Because the soil surface is the most interactive zone to rainfall and runoff events, increased soil test P levels at the 0- to 15-cm depth, particularly in the NT system at Coffeeville where incorporation did not occur, has implications for increased risk of off-field P movement and may contribute to the eutrophication of water bodies. For the same BL rate, no significant difference in soil character was obtained between BL alone and a combination of BL with supplemental N. At both locations, application of BL at rates greater than 4.5 Mg ha⁻¹ with 67 kg ha⁻¹ supplemental N did not increase cotton lint yield and exceeded the crop N use potential as evidenced by increasing soil profile NO₃-N. To minimize end-of-season soil NO₃-N levels, BL application to cotton at the optimum rates of 4.5 Mg ha⁻¹ with 67 kg ha⁻¹ supplemental N could be considered as a good management practice for cotton production.

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